World Journal of Agricultural Sciences 18 (3): 144-151, 2022
ISSN 1817-3047

DOI: 10.5829/idosi.wjas.2022.144.151

Soybean Yield Response and Net Benefit of Gain to Liming and Applied P Fertilizer and their Intermingling Effect on Selected Chemical Property of the Soil at Bako Area, Western Ethiopia

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Abstract: A field experiment was carried out at Bako Agricultural Research Center during 2012-2015 cropping seasons to investigate the synergy and to identify economically viable mixes of lime and P fertilizer in improving soybean productivity and acidic properties of the soil. Factorial combinations of four lime levels (2.3, 3.45, 4.6 and 5.75 t ha^{-1}) and four P rates (23, 34.5, 46 and 57.5 kg P_2O_5 ha^{-1}) were laid out in Randomized Complete Block Design (RCBD) with three replications. The results of the study showed that the highest grain yield (4.37 tons ha^{-1}) was recorded from the use of optimal (100% rec.) amount of P_2O_5 with slightly over optimal (125% rec.) level of lime. In the other standpoint, the soil laboratory analytical result after harvest showed that the highest soil pH (6.22) was recorded from the combination of 5.75 t lime ha^{-1} and 34.5 kg ha^{-1} of P_2O_5. Conversely, the exchangeable acidity was significantly reduced to 0.52 cmol (+) kg^{-1} due to application of the highest dose of lime (5.75 t lime ha^{-1}) that improved the potential acidity level of the soil by 196%. The highest soil available P (21.99 mg kg^{-1} of soil) was recorded from the plots treated with 5.75 tons ha^{-1} of lime and 57.5 kg ha^{-1}P_2O_5. The laboratory test result showed that all tested soil parameters were affected by the interaction of lime and P in which the highest records of the soil attributes were obtained from combinations of the higher doses of lime and P rather than the lower ones. On the whole, the result of this study indicated that the subsequent acid soil management intervention should be made through the use of optimal mixes of lime and P fertilizer to sustain the soil and soybean productivity in these and other parts of the country with similar agro-ecology. Therefore, based on cost benefit analysis, application of 5.7 ton/ha lime with 23 kg P_2O_5/ ha was economically acceptable to soybean producer on acid soil areas.

Key words: Soil Acidity · Soil Fertility · Liming Frequency · Optimal Combination

INTRODUCTION

Soybeans grow best on soils of medium to high fertility and with favorable soil pH. Maximum yields are possible only when producers meet plant nutritional requirements and other basic production factors [1]. Even if you use the best soybean varieties and cultural practices, your soybeans will not reach their full potential unless soil fertility and its acidity level is properly managed [2]. Adequate soil fertility and the ideal pH range of the soil helps reduce risks from weather stresses, diseases and nematodes, allowing plants to achieve maximum potential.

Soybean is an important multipurpose crop that has recently been introduced to smallholder farmers in Ethiopia as source of food and protein source for resource poor farmer who cannot afford to obtain dairy products. This pulse crop is currently serving as an income generating commodity and is being utilized as raw material in food processing industry in the country [3]. An increasing importance of soybean in Ethiopia is also shown in agriculture through counteracting depletion of plant nutrients especially nitrogen in the soil resulting from continuous mono-cropping of cereals, especially maize and sorghum, through biological nitrogen fixation, due to the presence of symbiotic bacteria

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Rhizobium japonicum in their roots [4] thereby contributing to increasing soil fertility.

However, acid soil infertility which has become a serious threat to crop production in most highlands of Ethiopia specifically in western part of Oromia caused by leaching of exchangeable cations (Ca^{2+} , Mg^{2+} , K+) and accumulation of high concentration of Al and other soil fertility degradation attributes are the main factors that adversely affect the soybean production in the country [5].In acid soils, availability of phosphorus, biological nitrogen fixation and microbial activity are reduced which in turn affects soybean development and yields. Reduced availability of Nitrogen (N) and Phosphorus (P) in predominantly acidic soils is responsible for reduced soybean performance through reduced photosynthesis and early root development, low microbial activity and poor nitrogen fixation, leading to low yields [6, 7].

Acidic unproductive soils maybe corrected through liming by reducing soil acidity to a level at which crop can produce its potential. Thus, liming acid soil makes the soil environment better for leguminous plants and associated microorganisms as well as increase concentration of essential nutrients by raising its pH and precipitating exchangeable aluminum [8]. The amount of lime required to adjusting the pH of the soil and its change over time in response to lime application depends upon the soil type, initial pH value of the soil and lime quality [9]. Soils with a high clay and organic matter content (greater reserve acidity) will require greater amounts of lime to neutralize acidity than a sandy soil lower in clay content and organic matter (lower reserve acidity) given that each soil has the same pH [10]. Soil pH declines faster in sandy (low CEC) soils than in soil with moderate to high clay content. Thus, the purpose of the present study was to study the relationships and magnitude of interaction between fertilizer and lime factors on yield of soybean and selected chemical property of the soil

MATERIALS AND METHODS

Description the Study Site: The experiment was conducted at Bako Agricultural Research Center during 2012-2015cropping seasons. The Center's experimental field is located at a latitude of 9°6'N and longitude of 37°9'E and at an altitude of 1650 m above sea level (Figure 1). The location has warm humid climate with annual mean minimum and maximum air temperatures of 13.5 and 29.7°C, respectively. The area received average annual rainfall of 1425mm (2012), 886mm (2013) and 1431mm (2014) with maximum precipitation being received in the months of May to August (Figure 2). However, monthly distributions of the rainfall through the cropping seasons were not similar (Metrological station of the center).The soil of the experimental site was reddish-brown, Nitisol, which is strongly acidic in reaction with a pH range of 5.0-5.4 according to the rating by Jones [11]. The area is a mixed farming zone and is one of the most important soybeans (*Glycine max* L.) growing belts in Ethiopia, in which cultivation of maize (*Zea mays* L.), finger millet (*Eleusine coronata*), common bean (*Phoseolus vulgaris* L.) and to some extent tef (*Erograstis tef*), are common.

Soil Sampling and Analysis: Soil samples (0–20 cm) were collected from the whole experimental field before lime application and from every experimental unit after each harvesting season randomly in zigzag pattern using an auger and core sampler. Soil samples were air-dried; gravels and non-decayed plant debris were removed and were ground to pass through 2mm and 0.5 mm screen prior to analysis. Soil pH was determined potentiometrically using pH meter with combined glass electrode in a 1:2.5 soil to water supernatant suspension [12]. The base titration method which involves saturation of the soil sample with 1M KCl solution and titrating with sodium hydroxide was employed to determine exchangeable acidity as described by Rowell [13]. Available soil phosphorus was extracted by the Bray II procedure [14] and determined colorimetrically by spectrophotometer.

Lime Rating and Fertilization: The amount of lime was determined based on the soil's exchangeable acidity (Al^{+3} plus H^{+1}) and bulk density with in 0.15m depth of the soil adapted from Kamprath [15] for liming acid mineral soils. Soil acidity ameliorant used in the experiment was calcite limestone of 95 CCE (Calcium Carbonate Equivalent) and fineness of 90 microns, while, the fertilizer source was TSP (Tri-Super Phosphate). The recommended rate of lime and P were 4.6 tons $ha^{-1}$and 46 kg ha^{-1}, respectively.

Experimental Design and Procedures: The experiment comprised four levels of lime (2.3, 3.45, 4.6 and 5.75 t ha^{-1}) which represented 50%, 75%, 100% and 125% recommended amount of lime respectively and four P rates (11.5, 23, 34.5 and 46 kg ha^{-1} P_2O_5) similarly representing 50%, 75%, 100% and 125% recommended P were combined factorially with one check and two controls, constituting a total of nineteen treatments laid out in RCBD with three replications. The linear model for the Two Factor Randomized Complete Block Design:

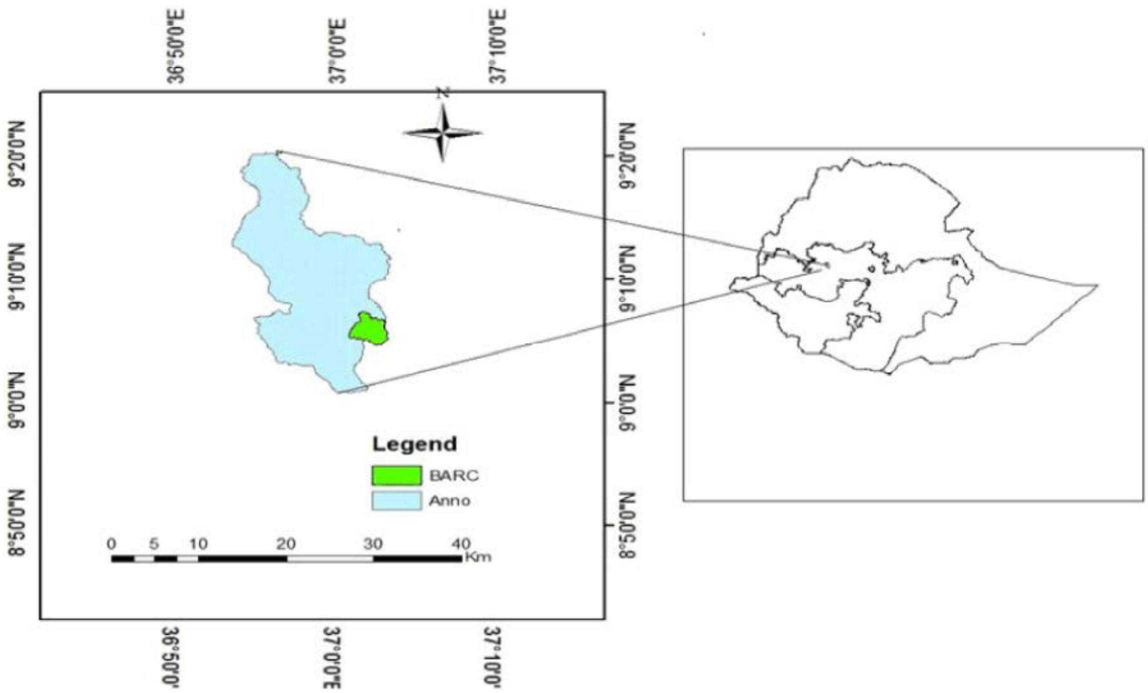

Fig. 1: Map of the study area: BakoAgricultural Research Center

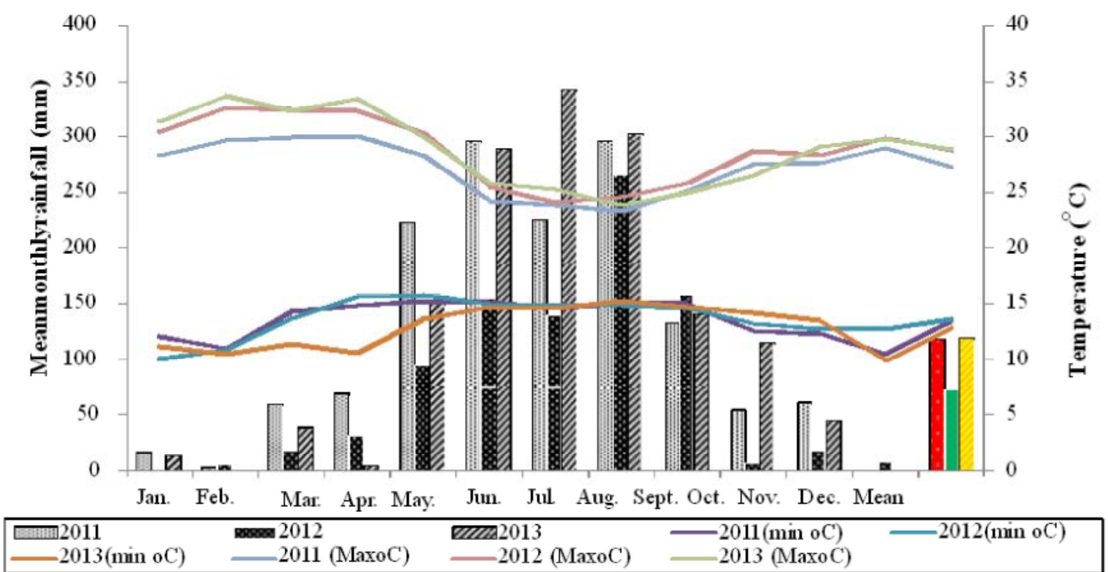

Fig. 2: Monthly rainfall, minimum and maximum temperature of crop growing seasons in Bako Agricultural Research Center (2011-2013)

$$Y_{ijk} = \mu + \alpha_i + \beta_i + \Upsilon_k + \alpha\Upsilon_{ik} + \epsilon_{ijk}$$

where, Y_{ijk} = the value of the response variable; μ = Common mean effect; α_i = Effect of factor A; β_i = Effect of block; Υ_k = Effect of factor B; $\alpha\Upsilon_{ik}$ = Interaction effect of factor A & factor B and ϵ_{ijk} = Experiment error (residual) effect

Lime was surface applied and incorporated with the soil by hand 60 days before planting. The test crop was a soybean variety of 'Boneya' recommended for Western Oromia agro ecological zone which was planted at intra and inter spacing of 40cm x 5 cm in gross plot area of 16m^2 after the P fertilizer had been applied per row and mixed with soil. Net plot area of 12.8m^2 was used for crop data collection at harvesting. Harvesting was done when 95% of the plants reached harvestable maturity. At physiological maturity, the above ground dry biomass of ten pre-tagged plants from the destructive rows was measured after oven drying the harvested produce at constant weight at 70°C for 48 hours. For obtaining the total aboveground dry biomass, the dry biomass per plant thus obtained was multiplied with total number of plants in net plot area and converted in to kg ha^{-1}. Seed yield was weighed and adjusted to 10% moisture content standard as recommended by Birru [16] according to the formula;

Adjusted yield (g/plot) = Measured yield × (100 – sample moisture content/100 – standard moisture content)

Data Analysis: Data were analyzed using SAS version 9.1[17] computer software and were subjected to ANOVA to determine significant differences among factors and their interactions. The result interpretations were made following the procedure [18]. Means were separated using LSD test. For all analyzed parameters, $P< 0.05$ was interpreted as statistically significant.

Partial Budget Analysis: The economically acceptable treatments were determined by partial budget analysis to estimate the gross value of the grain yield by using the adjusted yield [19] at the market value of the grain and inputs during the cropping period. Current prices of soybean, TSP and cost of lime were considered as variable with their cost. To estimate economic parameters, soybean yield was valued at an average open market price of 35.00 Birr/kg. To equate the soybean grain yield with what a farmer would get, the obtained yield was adjusted downward by 10%. Both the costs and benefits were converted to monetary values in Ethiopian Birr (ETB) and reported per hectare. Treatments net benefits (NB) and TCV were compared using dominance analysis.

RESULTS AND DISCUSSION

Soil Physico Chemical Properties of the Study Site

Effects of Lime and P Fertilizer on Soybean Grain Yield: The result of the study showed that seed yield of soybean was significantly affected by interaction of lime with P fertilizer application. A combination of lime and phosphorus fertilizer resulted in higher grain yield than that with lime or P used independently. The highest grain yield (4.37 tons ha^{-1}) was recorded from the use of sub optimal (75% rec.) amount of P_2O_5 with slightly over optimal (125% rec.) level of lime, whereas the lowest grain yield (1.72 tons ha^{-1}) was recorded from the absolute control with no lime amendment and fertilizer input (Figure 3) which gave a grain yield advantage of 154% over the no input experimental unit. This could be due to liming that reduced the exchangeable acidity (neutralizing the effect of Al^{3+} and H^+, raising the soil pH), enhanced soybean root performance, affected the solubility and availability of most of the plant nutrients, raised the level of exchangeable base status and improved soil structure. The results of the present study are in compliance with the work [22] who had reported the highest seed yield (1488.4 kg ha^{-1}) of haricot bean from the combination of 30 kg P_2O_5 ha^{-1} and the recommended amount of lime. Comparable investigation on soybean by Vongvilay *et al.* [23] illustrated that liming had beneficial effects on soybean where yield of soybean was improved significantly compared with the control. The seed yield obtained from the experimental plot that received recommended lime alone (2.06 tons ha^{-1}) was lower than that of the plot treated with sole recommended P; however, it was significantly higher than that of the control plot (1.72 tons ha^{-1}), the increment of which were 19.76%. Similar findings have been reported by Kamara *et al.* [7] who found significant effects of lime and P fertilizer on grain yields, The positive effects of lime on soybean productivity could be due to liming which increased soil nutrient availability through mobilization (P) and N fixation by microbial activity in which more crop nutrient demands were met. This result is in concordance to the finding of Andy and Abdullah [24] that explains application of lime and p fertilizer at similar rate increased seed yield by166-188% compared to no lime and fertilizer application elucidate that liming alone cannot serve to achieve the maximum potential of an acid soil.

The Interacting Effect of Lime and P Fertilizer on Selected Chemical Property of Soil

Soil pH and Exchangeable Acidity: Soil analytical result after harvest showed that the combined use of lime and P fertilizer increased soil pH and exchangeable acidity. The highest soil pH (6.22) was recorded from the combination of 5.75 t lime ha^{-1} and 23 kg ha^{-1} of P_2O_5 while the lowest soil pH (5.21) was recorded from non-lime amended and unfertilized plot which corresponded to an increase of 19.4% over the control (Table 3). Conversely, the exchangeable acidity was significantly reduced to 0.52 cmol (+) kg^{-1} due to application of the highest dose of lime (5.75 t lime ha^{-1}) and three quarter of recommended P (34.5 kg P_2O_5 ha^{-1}) that improved the potential acidity

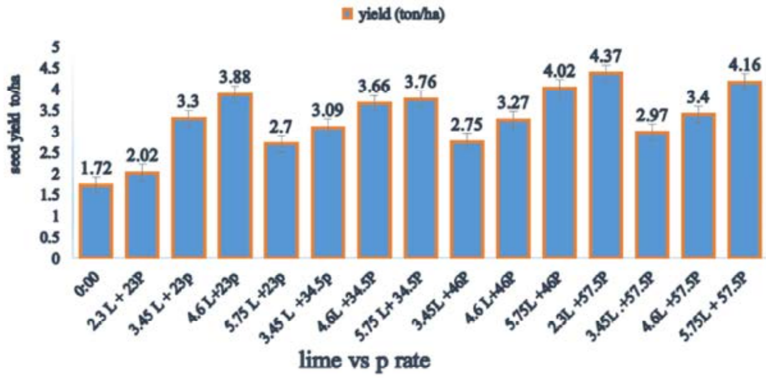

Fig. 1: Seed yield of soybean as affected by the interaction of P fertilizer and lime application

level of the soil by 196%. The raise of soil pH and decline of the soil exchangeable acidity might be due to reduction in H^+ and Al^{+3} ions concentration in the soil solution by buffering ability of applied lime. The result of this study is in conformity to the observation [25] who reported that soil pH increased from 5.03 to 6.72 and exchangeable acidity (EA) was significantly reduced due to the application of 3.75 t lime ha-1 on Nitisol with an inherent property of high P fixation in southern Ethiopia. A concordant examination was done by Getachew *et al.* [26] which showed that Application of 0.55, 1.1, 1.65 and 2.2 t lime ha^{-1} decreased Al^{3+} by 0.88, 1.11, 1.20 and 1.19 mill equivalents per 100 g of soil and increased soil pH by 0.48, 0.71, 0.85 and 1.1 units, respectively. The findings observed on soil pH and the exchangeable Al changes in soil agree with the findings of many authors [27-29] who reported the increase of 0.4 to 0.9 units of soil pH after lime application and the reduction of exchangeable Al and Aluminum saturation to adequate levels following application of lime in acidic soil.

Soil Available Phosphorus: According to the result of the current study, the highest soil available P (21.99 mg kg^{-1} of soil) was recorded from the plots treated with 125 % rec. lime (5.75 tons ha^{-1}) and 100 % rec. P (46 kg ha^{-1} P_2O_5) while the lowest soil available P (10.3 mg kg^{-1} of soil) content was recorded from the non-treated control plots. This sizeable increase in available P could have been caused by quick action of lime in improving soil acidity and enhancing microbial activity for mineralization of organic P when optimum pH is attained and hence phosphorus availability is realized [30]. Another reason for this scenario might be the effect of external application of P fertilizer which is better extricated from fixation as insoluble phosphates due to the lime conditioned environment of the soil. In line with this result, Kisinyo [31] pointed out that both lime and P fertilizer applications are important to enhance soil available P in acid and P deficient soil. Similarly, Fageria *et al.* [32] reported an increase of soil phosphorus as pH increased due to liming from 5.0 to 6.5, due to release of P ions from Al and Fe oxides, which are responsible of P fixation. Anetor and Akinrinde [33] reported that un amended soil remained acidic (pH 4.8), but liming raised pH (6.1-6.6) and resulted in maximum P release (15.1-17.3 mg kg^{-1}) compared to un-amended soil (4.2-7.1 mg P kg^{-1}) where application of lime and P increased plant tissue P, Ca and Mg concentrations.

Partial Budget Analysis: The results of this study revealed that the total grain yield significantly increased with the application of P_2O_5 and lime and attained maximum value as compared with the control (Table 3). Accordingly, highest grain yield was recorded for 23kg P_2O_5 ha^{-1} with 5.7 ton ha^{-1} lime application. As indicated in Table 3, the highest net benefit was obtained in response to the interaction of 23kg P_2O_5 ha^{-1} and 5.7ton ha^{-1} lime (9524.5 ETB), with marginal rate of return (MRR) of 1122.1, followed by 46kg P_2O_5 ha^{-1} with 4.6 ton /ha lime with net benefit of8165ETB, (Table 3).

The highest marginal rate of return obtained showed that further earnings could be obtained by application of beyond 46 kg P_2O_5 ha^{-1}. According to the manual [19], for economic analysis, application of fertilizer with the marginal rate of return above the minimum level (100%) is economical. But, 23 kg P_2O_5 ha^{-1} with 5.7 t ha^{-1} of lime was found to be economically feasible as compared to the other treatment combinations. Generally, interaction of phosphorus fertilizer with lime for the production of soybean on acidic soil in Bako district of western Ethiopia was economically feasible.

Table 1: Some physical and chemical properties of the soil of experimental site

Parameters	Test Result	Rating	Source
Sand (%)	45.28		
Clay (%)	38.36		
Silt (%)	16.36		
Textural Class	Sandy clay loam		
pH H_2O (1:25)	5.05	Strongly acidic	[20]
Exchangeable acidity (meq/100 g soil)	2.29	High	[21]
Available phosphorus (ppm)	8.52	Low	[11]

Table 2: Soil acidity attributes and soil available phosphorus content as affected by the interaction of lime and P fertilizer applied

Treatments	pH	Ex.Ac.(cmol (+) kg^{-1})	Ex.Al. (cmol (+) kg^{-1}).	Av.P. (mg kg^{-1} of soil)
5.75 t ha^{-1} lime + 23 kg $ha^{-1}P_2O_5$	5.88^{bc}	0.53^{h}	0.08^{def}	17.46^{de}
5.75 t ha^{-1} lime + 34.5 kg $ha^{-1}P_2O_5$	6.22^{a}	0.69^{efg}	0.06^{ef}	16.76^{e}
5.75 t ha^{-1} lime + 46 kg $ha^{-1}P_2O_5$	6.05^{ab}	0.52^{h}	0.16^{cd}	18.17^{de}
5.75 t ha^{-1} lime + 57.5 kg $ha^{-1}P_2O_5$	5.88^{cb}	$0.72^{d\text{-}g}$	0.05^{f}	21.99^{a}
2.3 t ha^{-1} lime + 23 kg $ha^{-1}P_2O_5$	$5.55^{e\text{-}h}$	0.88^{cb}	0.35^{b}	16.88^{de}
2.3 t ha^{-1} lime + 34.5 kg $ha^{-1}P_2O_5$	5.76cd	$0.71^{d\text{-}g}$	$0.13^{c\text{-}f}$	21.47^{ab}
2.3 t ha^{-1} lime + 46 kg $ha^{-1}P_2O_5$	5.74^{efg}	0.83^{bcd}	0.078^{def}	18.22^{cde}
2.3 t ha^{-1} lime + 57.5 kg $ha^{-1}P_2O_5$	5.38^{h}	1.12^{a}	0.44^{a}	21.36^{ab}
3.45 t ha^{-1} lime + 23 kg $ha^{-1}P_2O_5$	$5.69^{c\text{-}f}$	0.72^{def}	$0.128^{c\text{-}f}$	18.69b-e
3.45 t ha^{-1} lime + 34.5 kg $ha^{-1}P_2O_5$	5.53^{fgh}	0.96^{b}	$0.13^{c\text{-}f}$	$18.84^{b\text{-}e}$
3.45 t ha^{-1} lime + 46 kg $ha^{-1}P_2O_5$	5.5^{gh}	0.79^{cde}	0.19^{c}	$19.89^{a\text{-}d}$
3.45 t ha^{-1} lime + 57.5 kg $ha^{-1}P_2O_5$	$5.66^{d\text{-}g}$	0.89^{cb}	0.07^{ef}	16.58^{e}
4.6 t ha^{-1} lime + 23 kg $ha^{-1}P_2O_5$	5.72^{cde}	0.59^{gh}	0.15^{cde}	21.3^{abc}
4.6 t ha^{-1} lime + 34.5 kg $ha^{-1}P_2O_5$	$5.7^{c\text{-}f}$	0.64^{fgh}	0.09^{def}	17.11^{de}
4.6 t ha^{-1} lime + 46 kg $ha^{-1}P_2O_5$	$5.6^{d\text{-}g}$	$0.71^{d\text{-}g}$	0.08^{def}	$19.13^{a\text{-}e}$
4.6 t ha^{-1} lime + 57.5 kg $ha^{-1}P_2O_5$	$5.65^{d\text{-}g}$	0.69^{efg}	0.15^{cde}	$19.85^{a\text{-}d}$
4.6 t ha^{-1} lime	5.75	0.88	0.15	17.4
46 kg ha^{-1} P_2O_5	5.28	1.67	1.37	18.35
Control	5.21	1.54	0.96	10.3
CV	4.09	18.3	21.06	20.15
LSD	0.15	0.11	0.07	2.18

LSD (0.05) = Least Significance Difference at 5% of Probability level, Ex.A = Exchangeable Acidity, Ex. Al = Exchangeable Aluminum, Av.P = Available Phosphorus. Means within a column followed by the same letter (s) or with no letter are not significantly different

Table 3: Cost benefit analysis of lime and P rate application for soybean production on acid soil area

LR t/ha	P_{rate} kg/ha	TVC in ETB	GY kg/ha	ADGY kg/ha	GFB in ETB	NB in ETB	MRR %
0	0	0	172.00	154.80	5418	5418	D
2.3	23	2249	256.00	230.40	8064	5815	D
3.45	23	2399	202.00	181.80	6363	3964.5	D
4.6	23	2548	330.00	297.00	10395	7847	D
5.75	23	2698	388.00	349.20	12222	9524.5	1122.1
2.3	34.5	3224	270.00	243.00	8505	5281	D
3.45	34.5	3374	309.00	278.10	9733.5	6360	D
4.6	34.5	3523	366.00	329.40	11529	8006	1101.0
5.75	34.5	3673	376.00	338.40	11844	8171.5	D
2.3	46	4199	275.00	247.50	8662.5	4463.5	D
3.45	46	4349	327.00	294.30	10300.5	5952	D
4.6	46	4498	402.00	361.80	12663	8165	1480.3
5.75	46	4648	437.00	393.30	13765.5	9118	D
2.3	57.5	5174	297.00	267.30	9355.5	4181.5	D
3.45	57.5	5324	340.00	306.00	10710	5386.5	806.0
4.6	57.5	5473	416.00	374.40	13104	7631	D
5.75	57.5	5623	391.00	351.90	12316.5	6694	D

LR= lime rate, TVC= total variable cost, GY=grain yield, ADGY, Adjusted grain yield, GFB = growth field benefit, NB =net benefit, MRR= marginal rate of return, D= dominance

CONCLUSIONS AND RECOMMENDATIONS

Soybean is an important crop that has recently been introduced to small holder farmers in Ethiopia as source of food and protein source and currently serving as an income generating commodity whose production has been practiced in Western part of the Ethiopia and is being utilized as raw material in food processing industry in the country. However, high acid soil infertility due to low soil pH caused by leaching of exchangeable cations (Ca 2+, Mg2+, K+) and high concentrations of Al and depletion of major plant nutrients (N, P and others) attributed to continuous cultivation with removal of nutrients by crop, along with inefficient use of production inputs have remained to be the major hindrances to secure needed harvest of this crop. Indeed, Soil acidity had inherently existed for long time but not well noticed in Ethiopia. It was lately recognized (identified) to be one of soil problem that creates hindrance to productivity in the agricultural sector. The menace of soil acidification cannot be completely eliminated at once; however, preventive measures such as liming can be adopted forthe remaining

Thus, a field experiment was conducted during 2012-2015 cropping seasons to investigate lime reaction in low pH soils and to identify economically feasible mixes of lime and P fertilizer that can maximize the productivity of soybean and improve selected soil chemical properties.

According to the result of the current study, all measured soil parameters were affected by interaction of lime and P fertilizer where application of lime and P reduced soil acidity and increased available P in which the higher dose of these inputs increased and maintained longer residual effects on soil pH, exchangeable acidity, exchangeable Al^{3+}available P and soybean grain yield than lower ones. Hence the present findings show that lime application has positive effect in reducing acidity and increasing soybean yield. Thus, reclamation of the soil physical and chemical properties and biological activities of a soil has great importance in increasing crop production. In general, application of 23 kg P_2O_5 ha^{-1} with 5.7 t ha^{-1} lime gave the highest (9524.5 ETB) net benefit with MRR (1122.1) were economically feasible and recommended for soybean production in the study areas as well as for similar agro-ecologies.

ACKNOWLEDGMENTS

The authors would like soil research team for their participation in data collection and compilation. We would also extend our gratitude to anonymous reviewers for their constructive suggestions.

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